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PHOTOGRAPHIC MATERIALS

# Color negatives at the demise of silver halides

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**ABSTRACT**

We are experiencing a technological revolution in photography – digital photography. Computers, electronic sensors and the Internet have almost completely replaced the analogous chemical photography based on silver gelatin. Today, all this material can be regarded as historical. It is an interesting fact to note, however, that we know relatively little about the photographic materials of the second half of the 20th century, i.e. the modern materials. This is especially true for color negatives. The goal of this work is to find information about the color negative process, to collect and characterize these materials, and to publish all data in a database.

## PART A: EDGE MARKINGS – NEW POSSIBILITIES OF DATING 35MM FILM

Commercial 35mm films have edge markings, which vary from film to film. A first analysis of a selected group of films showed that more than 20 different features can be distinguished. The results show that this dating method does work for color negative films; this is also the case for color slide film, albeit with reservations. This article is the first to give an overview of common and important edge markings and presents the sources used in the study.

### Material and source situation

The presented publication explores edge markings on 35-size films in a systematic way. Up to now, the use of edge markings as dating aid has been mainly studied in relation to motion picture film (Brown 2000). The use of *notch codes* in still photography to identify sheet film has already been investigated (Horvath 1987). Monographs relating to small-format photography were so far limited to practical guidance for amateur photographers or to specific camera models. A scientific examination of small-format film has so far hardly ever been done, due to its low value and prestige, perceived as mass photography, as opposed to 19th- and early 20th-century photography.

The source situation was thus rather tenuous, and is getting even worse since film producers have largely disappeared from the market. In addition, product information on (small-format) films was "not library- or archival-quality" information, "but served as user information for photographers and photo labs,"[1] therefore manufacturers were not interested in their systematic preservation in the past. The disappearance of analogue photography is also a threat to information: "While photographic devices . . . have been systematically collected and researched, there is virtually no systematic collection of photographic materials in photographic museums or archives according to the principles of photo-technology."[1]

Against this background, the collection activities of Gert Koshofer were a stroke of luck. For several years, he has published a series of articles that list trade names, manufacturers' names, sensitivity data, production data and technical details for around 1,300 photographic films from all over the world.[2]

Until now, 758 different color films have been analyzed from manufacturers such as Eastman Kodak, Fujifilm, Agfa-Gevaert, Ilford, 3M and others that dominated the world market for small-format photography from the 1930s to the end of the millennium.

### Historical film database

The collected records and film samples as well as important sources (I3A DX codes for 135-size film,[3] list of Kodak librarians until 1989[4]) are recorded in an online database (http://www.bilderdienst.ch) and made available on request to researchers for collaborative research. The evaluation of the acquired characteristics is provided – differentiated according to individual characteristics and characteristic combinations. The historical 35mm film database also provides a list view of film types according to manufacturers, which also includes their production times. The list view can be filtered according to requirements of manufacturer or film type. Results can optionally be displayed with or without image reference.

The main tool of the database application is the search function for the identification of films by means of edge markings. Individual edge features or arbitrary feature groups can be selected and thus the films can be checked.

A user account has been set up for the participants of the ICOM-CC 2017 Conference (URL: http://www.bilderdienst.ch; username: icomcc2017; password: Fotografie2015). This enables the illustrated example to be traced using the database.

### Edge markings: An example

In order to illustrate the variety of edge markings on small-format films, a color negative pattern is considered in more detail below. The example has been chosen carefully because it covers a large part of the observed features.

The sample is a Fujicolor Superia 200 that was produced in the sensitivity of 200 ASA from 1999 to 2005. This film has a wide variety of features: a frame count can be found on the top and bottom, a half-frame count on the top and bottom, a continuous thin color strip in magenta on the top and bottom, and broken lines in green on the top and bottom, closer to the center of the film.

It is also possible to read the manufacturer name, "FUJI," as well as the designations "S-200" and "F80" (production/emulsion number), and "CA-6" (CA = Superia). While the "S-200" label can be found over all four images and be said to be redundant, the designations "FUJI," "F80" and "CA-6" can only be observed once over the four images and are therefore slightly redundant (Figure 1).


**Figure 1.** Fujicolor 200 Superia

It is also worth noting that the DX coding is found at the bottom edge of the filmstrip (Figure 2). There are 11 vertical lines between the start and stop bits, in which the lower lengths of the image shown on the right side vary from image to image. This advanced DX coding was introduced from 1990 and encodes the image or field number of the film.[5] It is therefore possible to speak of a short DX coding with seven dashes or a long DX coding with eleven dashes.

The addition of the frame number on the top and bottom, the half-frame number at the top and bottom, the picture stripes and dashes in magenta and cyan, the DX coding and the manufacturer and other names sum up to ten features.


**Figure 2.** DX film edge code (see Note 4). Fujicolor Superia 200: 6 bits start (black), 7 bits DX Number Part 1 (0001000=8=Fuji) (red), 1 bit unassigned (black), 4 bits DX Number Part 2 (1101=13=Superia 200) (green), 9 bits for frame number (000101000=5, 000101101=5A) (blue) and 4 bits stop (black). The upper part serves for syncing

### The systematics of characteristics

After evaluation of all film samples, a list of 24 features to characterize edge markings could be compiled (see Table 1).

**Table 1.** The 24 edge marking features

| No. | Feature type | Possible values |
|---|---|---|
| 1 | frame no. on top | yes, no |
| 2 | half frame no. on top | yes, no, whole number, A & B |
| 3 | frame no. on bottom | yes, no |
| 4 | half frame no. on bottom | yes, no, whole number, A & B |
| 5 | Alignment of count on top | no value, from right to left, rotated 90°, rotated 180° |
| 6 | Alignment of fonts on top | no value, from right to left, mirrored |
| 7 | Alignment of count on bottom | no value, turned 90° |
| 8 | Alignment of fonts on bottom | no value, mirrored |
| 9 | Perforation on top: count | no value, 1, 2 |
| 10 | Perforation on top: color | no value, blue, green, magenta, magenta and green, black |
| 11 | Perforation on top: shape | no value, dots, squares, strips, strips and dashes, dashes, dashes and strips |
| 12 | Perforation on top: grouping | no value, pairs, triples |
| 13 | Perforation bottom: count | no value, 1, 2 |
| 14 | Perforation bottom: color | no value, blue, yellow, gray, green, green and magenta, magenta, magenta and green, red |
| 15 | Perforation bottom: shape | no value, triangles, half-moons, dots, squares, diamonds, strips, strips and dashes, dashes, dashes and strips |
| 16 | Perforation bottom: grouping | no value, singles, pairs, triples, quadruples |
| 17 | Further features below or besides the perforation | no value, white dot above perforation, square and rectangle below perforation |
| 18 | Bar code on top | yes, no |
| 19 | DX code on bottom | yes, no |
| 20 | DX code type | no value, short, long |
| 21 | Number code four digits | no value, 1000–9999 |
| 22 | Number code three digits | no value, 100–999 |
| 23 | Mixed codes, characters and numbers | representation of manufacturer names, product names, sensitivity information, emulsion codes, etc. |
| 24 | Coding of support | Nitrate Film, Safety Film (e.g. S.afety, Sa.fety, Saf.ety etc.) Film (Kodak Manufacturing code) |

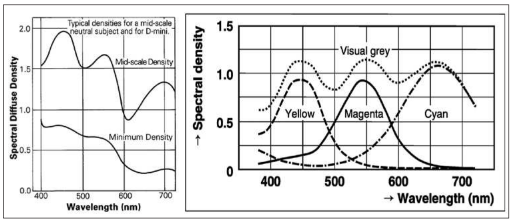


**Figure 3.** Published spectral absorbances of modern photographic film. Left: Integral densities of negative Fujicolor Superia 200 (Fujifilm, data sheet ref. no. AF3-008E, 03/2008). Right: Analytical densities of reversal Agfachrome RSX II 100 (Agfa-Gevaert, technical data F-PF-E4, 07/2003, 4th edition)

While features 1 to 20 are highly redundant and can thus be observed with every image, features 21 to 24 are those which are generally less redundant. They rarely appear with every image but usually only with every second, fourth or maximum sixth image.

### Possibilities and limitations

Color negative films have on average 6–7 features and can be positively identified with a high probability. The dating period can also be better defined. Slide films, on the other hand, are more difficult to characterize. This is because the DX code has only been used with color negative films. In contrast, color transparencies are usually framed as single images and have fewer features.

### Consequences for digitization

The results of the investigation have a direct consequence for the long-term preservation and development of photo inventory in archives and image collections. Since image contents can only be read correctly in the right context and dating is essential for this, edge markings must be included in the process whenever image media are digitized. To focus solely on the image content means to deprive oneself of the possibility of reading the photographs in their context. But also the long-term preservation of the photographic materials as a means of further recourse to originals is indispensable.

## PART B: A SPECTROSCOPIC DATABASE OF COLOR FILM

### Principles of modern subtractive color photography

The emulsion of a modern subtractive color film, after exposure and processing, consists of three adjoining layers that contain the image-forming dyes (yellow, magenta and cyan). The *spectral absorbance* specifies numerically their absorptions for each wavelength of the visible range; the typical normalized absorption spectra of the single dyes (in the following called *analytical densities*) are reported on the right of Figure 3. The overall absorption of all three dyes, which is called *integral density* (Figure 3, left), varies across the film frame in relation to the local dye concentration triad, producing the multitude of colors characteristic of the specific film.

The above depiction is quite accurate for reversal film (color slides). Negative films, on the other hand, are more complicated due to the masking for color correction (Hanson 1950) that gives them the characteristic orange cast. From the 1950s on, in a color negative there have been actually five dyes: yellow, magenta and cyan, plus two other correcting dyes.

### Relevance of a spectral database

During the “mature age” of photography, the economic competition in creating successful recipes between photographic companies resulted in a myriad of film products characterized by different analytical densities and different masking dyes. Nowadays, the availability of a comprehensive spectral database of color film brands would provide an additional opportunity to identify unknown photographic samples and finds, potentially achieving historical information about their age and provenance. The analytical densities are independent of the image content, representing an appropriate constituent of the spectral database. Such a database does not yet exist.

In recent times, major companies published quite detailed technical datasheets of their products, but these publications cover only a small portion of the information necessary for a usable spectral database. The available technical datasheets of color negatives show only integral densities (see for instance Figure 3, left); the analytical densities are included only for reversal material of recent production.

The photographic companies were routinely measuring the analytical densities of their products during the fabrication, creating single-dye films for quality-monitoring purposes. Nowadays, the production plants of color film are disappearing, and the possibility to have access to technical information directly from the manufacturer is vanishing. The scientific analysis of this kind of material is thus entering the domain of archaeometry.

### Methods for determining the analytical densities

In view of the above, embarking in the creation of a spectral database of color films necessitates carrying out new spectroscopic measurements. In this regard, it has to be considered that it is not feasible to mechanically separate the emulsion layers, and therefore the measurement of the spectral absorption with a simple setup source/film/spectrometer generally provides the overall absorption of all dyes (i.e., the integral density). Even though the image of a modern film is constituted by well-circumscribed color elements of micron scale (*dye clouds*),[6] a transversal transmission measurement encompassing the absorption of one dye only has been demonstrated impracticable, even at very high magnification. The different dye-cloud types always overlap (data not shown).

The following of this paper describes two viable methods to determine the analytical densities of color film. The data presented were collected from reversal film of recent production, for which the manufacturer published the analytical densities, so it was possible to validate the results of the methods by comparing the obtained spectra with the published spectra.

### Statistical approach

A statistically significant set of absorption measurements can be actually processed to unravel the simple tri-variant underlying structure. Many processing methods (Keshava 2003) have been developed and tested on hyperspectral images (essentially being a multitude of spectral measurements disposed in array) to decompose the measured spectrum of a mixed pixel into a collection of constituent spectra *(endmembers)*, and a set of corresponding fractions *(abundances)*. This procedure is called *spectral unmixing*.

For the identification of the proper algorithm to be used, it is necessary to delineate a model that describes how the absorptions of the dyes blend together in a color film. Luckily, a processed color film is quite optically homogeneous, thus it is possible to model it as a linear system, assuming that at any wavelength the absorbance of each emulsion layer is proportional to the local dye concentration (and to its extinction coefficient and layer thickness), and the overall absorbance of the film is equal to the sum of the absorbances of the single layers. According to this model, Ohta (1973) suggested a procedure to infer the analytical densities from the integral densities of a comprehensive set of saturated colors of the film. By applying a *Principal Component Analysis* (PCA) on the spectra measured, a prominent difference is generally found between the third and fourth *eigenvalues*, consistently with the number of independently variable components. The real absorbance spectra of the constituent dyes might be estimated by finding the proper linear combination of the principal *eigenspectra;* Ohta suggests narrowing the range of possible linear combinations by supposing reasonable assumptions (e.g., spectral absorptions and concentrations of the dyes are always non-negative). Trumpy and Flueckiger (2015) achieve an approximation of the spectra of the dyes by performing a minimization with a linear least-squares method to the ideal block dyes. In the field of remote sensing, Nascimento and Bioucas-Dias (2012) and Plaza et al. (2012) recently proposed various unsupervised hyperspectral unmixing methods for linear data sets without pure pixels. These methods, which have been routinely used in hyperspectral remote sensing, can also be used to unmix hyperspectral imagery collected from color film.

**Sectional approach**

The direct measurement of the analytical densities of a color film is impracticable with transversal transmission measurement; hence cutting film thin sections sets out to be the only viable way. If a fragment of film with a very small width is cut transversally, it is likely to fall on its side. These thin sections can be analyzed at the microscope to display the layered structure of the film (as admirably shown by the Image Permanence Institute[7]). The disadvantage of this method, unlike the previous approach, is that of being destructive. To reduce the damage, the small fragment can be cut from a portion of the film that does not contain the photographic image, so that the essential part of the film is not compromised. A fragment was cut from a reversal Kodak Ektachrome 64T with the use of a microtome. The thickness of the acetate base was 0.18 mm, hence a cut of ca. 100 µm was small enough to let the section fall on its side and be placed on a microscope slide. The gap between the slide and a coverslip was filled with distilled water, which induced the swelling of the gelatin, making the emulsion layers thicker and better separated.

The sample has been measured with a microscopic spectrophotometer specifically designed to carry out absorption measurements circumscribed to small areas. A fiber-optic spectroradiometer (FS3, PANAlytical) has been coupled with a 100× microscope objective, which focused the light transmitted by the thin section on a white screen (Figure 4, right). The screen had a hole in the center where the 1-mm-thick optical fiber of the spectrometer collected the light corresponding to an area on the film of 10 µm in diameter.

The result of this experiment is reported in the plot of Figure 4. The measured absorptions look well separated, each of them encompassing only one emulsion layer. Interestingly enough, the measured analytical densities are significantly broader than those published by the vendor, and the measured side absorption of the magenta dye in the blue region is stronger. Moreover, the absorption maxima do not exactly match, with a significant shift especially observed for the yellow dye between the published (ca. 440 nm) and measured (ca. 450 nm) data.

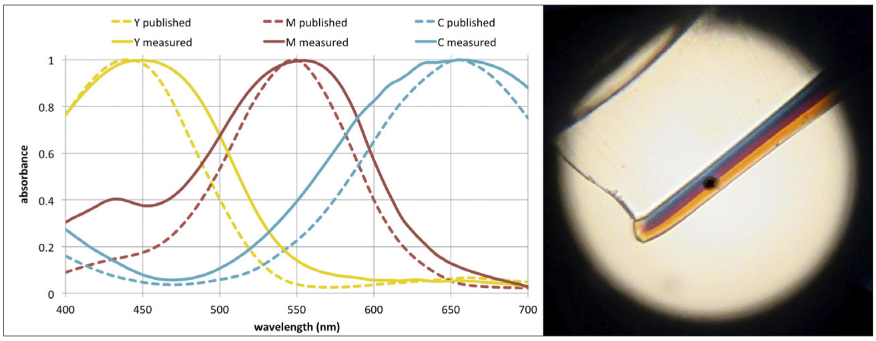


**Figure 4.** Left: Analytical densities of reversal Kodak Ektachrome 64T. Measurement with the "sectional approach" (solid lines), and data published by Kodak (dashed lines). Right: Magnified image of the measured thin section. The optical fiber collects the transmitted light in the center of the image

## CONCLUSION

Edge markings are a good and simple tool to characterize color negative material. Spectroscopic methods still require a great deal of research, the source situation for spectral data is sparse, the color masking complicates the statistical approach and the sectional approach is destructive and needs complex equipment.

## NOTES

[1] Cited from a German publication by R. Gschwind, "Virtualität, Materialität und Funktionalität", in *Über den Wert der Fotografie, zu wissenschaftlichen Kriterien für die Bewahrung von Fotosammlungen,* 2013, Baden, hier + jetzt Verlag, ISBN 978-3-03919-277-9.

[2] Koshofer, G. See the article series *50 Jahre moderne Farbfotografie – Farbfilme des Weltmarktes* 1936–86 by Gert Koshofer, which was published in 27 parts in MFM Fototechnik between June 1986 and July 1988, as well as a second, shorter series entitled *Die Farbfilme des Weltmarktes von 1986–1996. Veränderungen und aktueller Stand*, published in MFM from March to June 1996.

[3] This refers to the DX codes for 135-size film of 2001 and 2008. The 2008 document is available online at https://www.yumpu.com/it/document/view/3454560/dx-codes-for-135-size-film-international-imaging-industry-association (accessed 21 August 2015).

[4] This is an unpublished list of Kodak products, which is compiled by several Kodak librarians and lists the Kodak products from the founding period up to 1989. The list is accessible via the repository of http://www.bilderdienst.ch.

[5] See David Bills-Thompson's "DXn Simulator – For decoding 35mm film cassettes and binary coded film strips" (http://www.imageaircraft.portfairy.town/DXsim/). See also the patent document US4965628 (Photographic Film with Latent Image Multi-Field Bar Code and Eye-Readable Symbols), which describes and explains the function and purpose of the DX coding. See http://www.google.com/patents/US4965628 (both accessed November 2016).

[6] Starting from the 1940s, when Kodak introduced oil-protected couplers, preventing their diffusion through the gelatin (Mees 1942, Fujita 2004).

[7] Image Permanence Institute–RIT's College of Imaging Arts & Sciences (IPI–RIT). Graphics Atlas, an object-based approach for the identification and characterization of prints and photographs, http://graphicsatlas.org (accessed 10 November 2016).

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